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Mechanism of Negative Corona Pulses in CO_2 - SF_6 Mixtures

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Abstract
Current waveforms of first negative corona pulses have been measured in CO_2-SF_6 mixtures over a pressure range extending from 6.65 kPa to 50 kPa and various overvoltages. Effects of changing cathode secondary electron emission were studied using a copper cathode coated by CuI and graphite. The results indicate a positive-streamer discharge mechanism and important role of field emission processes at pressure above 30 kPa.

1. Introduction

Mixtures of SF_6 with other less expensive gases such as air, N_2 and CO_2 are extensively investigated as a cheaper and environmentally attractive option to pure SF_6. Also, comparing to pure SF_6, there are indications of the superior dielectric characteristics of these mixtures in non-uniform field conditions and in the case of projection-initiated breakdown. Since in these conditions the breakdown criteria often can be interpreted as the negative corona-onset voltage [1,2,3], it is apparent that a better understanding of the negative corona mechanism in SF_6 and the SF_6 containing mixtures can help to optimize their insulation performance.

In a recent series of papers [4,5] it has been concluded that in air-SF_6 and N_2-SF_6 mixtures containing less than approximately 10 % of SF_6 the negative corona pulse is associated with the formation of a cathode-directed streamer-like ionizing wave in the immediate vicinity of the cathode [6]. However, in the mixtures containing more than 10 % of SF_6 the ionizing wave was quenched and, consequently, the discharge was governed by the Townsend ionization mechanism fed by cathode γ_p -emission processes. This work is now being extended to study the negative corona pulse mechanism in CO_2-SF_6 mixtures.

2. Experimental results and discussion

The point-to-plane electrode system consisted of a hyperbolically capped Cu-cathode with a value of tip curvature radius of 0.1mm situated 12 mm from a planar stainless steel anode. The experimental set-up and procedure were similar to those given in Refs. [4,5]. To clarify the role of γ_p – emission processes, copper iodide and graphite, which have exceptionally high and exceptionally low photoelectric yields, respectively, were used as alternative cathode surface materials to cooper [4,5,7,8].

Figure 1 shows the first corona current pulses measured in CO_2-SF_6 at a pressure of 6.65 kPa for the SF_6 percentage varied from 0% to 30%. From Fig.1 it is apparent that increasing the SF_6 content a more significant reduction in the step height on the pulse leading edge than in the pulse maximum was observed, which is in contrast to the observed discharge behaviour in SF_6 with N_2 and air mixtures [4,5].

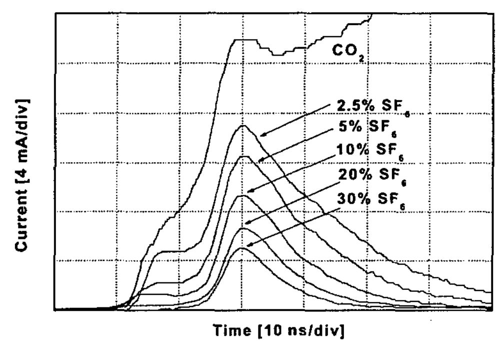

Fig. 1: Current pulse waveforms taken for various SF_6 admixtures at a gap voltage value of 3 kV and a pressure of 6.65 kPa.

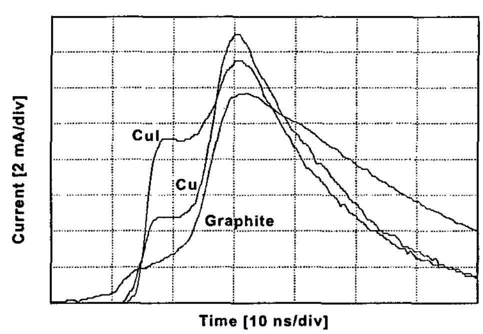

Fig. 2: First negative corona pulses measured using the Cu-cathode, the CuI-cathode and the graphite-coated cathode for CO_2 at a pressure of 6.7 kPa with 2.5% SF_6 at gap voltage value of 3 kV.

Figure 2 compares the first corona pulses measured at a pressure of 6.7 kPa using the copper cathode, CuI-coated cathode, and graphite-coated cathode for 2.5% of SF_6. The observed sensitivity of the step height and relative insensitivity of the pulse maximum to the changing the cathode γ_p – emission, which are identical with the discharge behaviour observed in SF_6-air and SF_6-N_2 mixtures [4,5], are also in a good agreement with the above mentioned streamer-based hypothesis for the discharge mechanism [6].

The first corona current pulses measured in CO_2-SF_6 at a pressure of 50 kPa for SF_6 content varied from 0% to 30% are shown in Figs. 3(a)-(b).

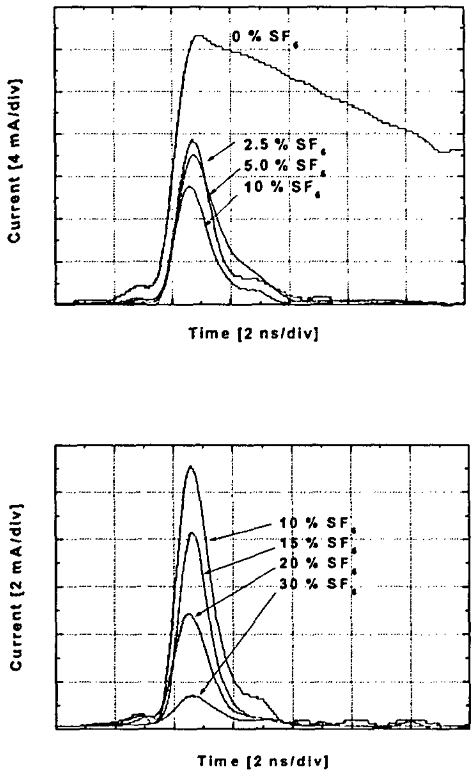

Fig. 3: Current pulse waveforms taken at a gap voltage value of 5 kV and a pressure of 50 kPa for SF_6 admixtures (a) 0%-10%; (b) 10%-30%.

At a pressure of 50 kPa the step on the pulse leading edge in pure CO_2 is less discernible than at 6.67 kPa apparently due to an increased collisional quenching of photon-emitting excited states and absorption of photons in the gas. The decrease may also be due to increased electron attachment near the cathode surface [9].

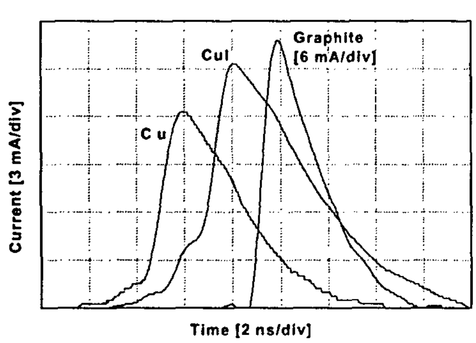

Fig. 4: First negative corona pulses measured using the Cu-cathode, CuI-coated cathode, and graphite-coated cathode at a pressure of 50 kPa in CO_2 + 2.5% SF_6, and at gap voltage value of 5.5 kV.

Figure 4 exemplifies the effects of changing of the cathode γ_p - emission using 2.5% of SF_6 and gap voltage of 5.5 kV, where the step on the pulse leading edge was clearly seen. In a close correspondence with the results shown in Fig. 2 and with the streamer-based hypothesis the graphite coating led to a dramatic reduction of the step on leading edge, while the CuI coating led to a well pronounced increase of the step. However, in a contrast to the results measured at a reduced pressure of 6.65 kPa, at 50 kPa the graphite coating resulted in a marked increase of the pulse magnitude. The observed effect of the graphite cathode coating observed at higher gas pressures is the same as that studied in more detail in work [5] for the discharge in N_2-SF_6 mixtures. On this base, and in line with the recent studies of other authors [10-12], we hypothesize that this effect can be an indication that with increasing gas pressure and consequently increasing gap voltage the field emission becomes to play an important role in the discharge mechanism.

3. Conclusions

The above results interpreted in terms of the streamer-based hypothesis suggest that the effect of adding SF_6 to CO_2 was primarily to quench the Townsend multiavalanche ionization processes, while the effect on the positive streamer ionization processes was much less pronounced. This is in contrast to our results obtained in similar experimental conditions in air-SF_6 and N_2-SF_6 mixtures [4,5], where the observed effect was opposite. One may therefore speculate that the stronger streamer quenching in N_2-SF_6 mixtures, and the resulting more efficient corona stabilization effects can be responsible for higher dc breakdown voltages measured at pressures less that 0.2 MPa in N_2-SF_6 mixtures, comparing to those measured in CO_2-SF_6 mixtures [13].

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